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HAWAII AGRICULTURAL EXPERIMENT STATION
E. V. WILCOX, *Special Agent in Charge.*

BULLETIN NO. 21

A Study of the Composition of the Rice Plant

BY

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AND
ALICE R. THOMPSON

UNDER THE SUPERVISION OF
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LETTER OF TRANSMITTAL

HONOLULU, HAWAII, *April 5, 1910.*

SIR: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 21 of this station a manuscript on A Study of the Composition of the Rice Plant, by W. P. Kelley, chemist, and Alice R. Thompson, assistant chemist. The uncertainty which has prevailed regarding the time at which fertilizers should be applied to rice, in order to produce their maximum effects, indicates the practical importance of the investigations herein reported. The chemical work, which has extended over two crops of rice, has brought to light some remarkably concordant results which have a direct bearing upon agricultural practice, and have also afforded data of considerable scientific value in an understanding of the effect of fertilizers and the reaction of plants to their application.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
JAMES WILSON, *Secretary of Agriculture.*

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A STUDY OF THE COMPOSITION OF THE RICE PLANT

INTRODUCTION.

For a number of years the use of fertilizers has enlisted the attention of an increasing number of chemists, and while nearly all of the important economic crops have been studied, rice appears to have received but scant attention.[1] This is due perhaps to the fact that rice for the most part is grown in countries where scientific agriculture is little advanced. It is true, this crop is chiefly grown in the Orient under a system that has effectively maintained the fertility of the soil for centuries, but it is equally true that but little scientific study of its fertilization has been made. Rice is grown in Hawaii almost exclusively by the Chinese; and while some dry-land rice is cultivated, possibly 99 per cent of the entire crop is grown in submerged culture. Influenced by the practice of applying fertilizers to sugar-cane when it is some months old, as is done by the sugar planters here, and following a modification of the system of partial application of liquid organic manures to rice culture in the Orient, the Chinese here apply chemical fertilizers to the rice just before the panicles burst from the leaf-sheath.

The rice soils of Hawaii are extremely porous and in spite of every effort to puddle these soils, there is considerable seepage from the submerging waters. Most growers maintain a submergence of about three inches of water above the surface of the soil, but if for any reason the inflow is shut off for a period of twenty-four hours a large percentage, and in many instances all, of this water will have passed below the surface. It is, therefore, only natural that the grower with little or no knowledge of the ab-

1 See Texas Sta. Bul. 82; Louisiana Stas. Bul. 77; South Carolina Sta. Bul. 59. Various publications relating to rice have been issued by the Japanese, some of which deal with the fertilization of this crop.

sorptive powers of soils should apply fertilizer at, or near, the time when it would seem most needed; and since it is grain, and not straw, that is wanted, the practice of late applications is the more easily understood. The custom simply involves the idea of feeding the plant at the time when it is considered to be most needed.

For several years this station has devoted some attention to the use of fertilizers for rice. In this work[1] it has already been shown that marked increases in the yields of straw and grain may be produced by the application of certain fertilizers. The fertilizer experiments previously made here have followed for the most part the usual plan employed in plat experiments. Various fertilizing substances have been applied and the economy of the application measured by the increased weight of the mature crop. Deductions concerning the deficiency of the soil as regards a given element are often drawn from similar observations and frequently from no other data. More and more, however, is it being recognized that for fertilizer investigations to be of the greatest value, other factors must be considered. The influence on absorption by growing plants brought about by the application of soluble fertilizers, the changes induced by such applications on the physics and biology of the soil, the chemical reactions thus set in motion, etc., are not fully understood. Therefore, it is important that we have a more fundamental investigation of these questions. It is not sufficient that the agricultural worker make applications of the already known principles for the benefit of farmers; he should also seek to better understand the questions involved.

Recognizing the economic importance of this crop and the need for scientific data regarding its fertilizer requirements, a series of plat experiments were begun on the rice trial grounds of this station in February, 1909. In addition to the influence on the total yields, it occurred to us that the composition of the plant at its various stages of growth might throw some light on the question of how a given fertilizer acts. Then a determination of the period in the development of the rice plant, during which the main portion of a given element is absorbed, is important as forming a scientific basis for the time of fertilizer appli-

[1] Hawaii Sta. Rpts., 1907, p. 67; 1908, p. 65.

cation. It is obvious that if the rice plant absorbs its potassium, for instance, previous to the flowering period, it is useless to apply this element at the time the Chinese usually make the application.

In order to guard against lateral movement of the fertilizers each plat was surrounded by low dykes, constructed of puddled soil and rendered practically impervious to the passage of water. The plats at one end bordered on an open flume from which, through narrow openings in the dykes, a slow stream of water was admitted to each plat. The amount of water thus admitted to a given plat was so regulated as to just equal the loss through evaporation, transpiration, seepage, etc., so that a constant submergence was maintained on all plats alike.

At the beginning of this investigation it was our intention to determine the minerals, nitrogen and the total carbohydrates in the plant at different periods of growth; but during the course of the work the rice was found to contain such large percentages of various carbohydrates, especially at certain periods in its development, that it was decided to also make a study of this point. This bulletin, therefore, deals with three phases of this subject, and will naturally fall into three parts, as follows:

1. A study of the composition of the rice plant as affected by fertilizers.
2. A study of the absorption of nutrients by the rice plant.
3. A study of the carbohydrates in the rice plant.

Description of Soil.

The uniformity of the plats used in this experiment had been determined by growing on them the same variety of rice without the use of fertilizers through two previous harvests, and the yields indicated that the soil throughout was extremely uniform. The soil is a coarse, stony loam, rather low in organic matter, neutral, and well drained. Both previous experiments and chemical analysis showed the soil to be well supplied with calcium.

The following table will show the mechanical structure and chemical composition of this soil:

COMPOSITION OF RICE SOIL.

Mechanical analysis.[1]		Chemical analysis.	
	Per cent.		Per cent.
Coarse gravel and stone...	27.4	Organic matter	10.11
Fine gravel	18.2	Lime	1.60
Coarse sand	10.1	Phosphoric acid	.48
Medium sand	4.8	Potash	.35
Fine sand	3.6	Nitrogen	.25
Silt	2.9		
Clay and fine silt	33.0		

The ten one-fortieth acre plats of this experiment were treated as follows: Three plats were not fertilized, forming, therefore, checks; the remaining seven each received different fertilizers, using the single elements on some, on others various combinations. Nitrogen, derived from ammonium sulphate, was applied at the rate of 60 pounds per acre, phosphoric acid, from superphosphate, at the rate of 45 pounds of phosphoric acid per acre; and potash, from sulphate, at the rate of 60 pounds of potash per acre. No lime was applied, since previous tests failed to indicate its need. After thorough preparation, the soil was flooded and left partially submerged for several days, after which the fertilizers were applied to the wet soil on February 6, thoroughly mixed with the same by hand and then completely submerged with a very pure artesian water, in which condition it was maintained throughout the experiment, with the single exception of a period of about five days during the flowering period. The water at this time was shut off in order to hasten backward fruiting stems and insure uniformity in ripening.

The rice-growers in Hawaii do not plant their rice in the fields where it is to mature, but in seed beds, where it germinates and grows until from twenty to thirty days old; then it is transplanted in clumps of from three to five seedlings in rows about ten by ten inches apart. In this experiment carefully selected seedlings from Japanese seed were transplanted on February 11 in clumps of threes, at a uniform distance of 9 x 10 inches apart. It may not be without interest to call attention to the uniformity of this rice. In the first place, the seed was

[1] The mechanical analysis was made by F. G. Krauss.

selected stock from a strain of rice that had been systematically bred in Hawaii for a number of generations; and secondly, a further selection was made at the time of transplanting, thus largely eliminating plants of low vitality, and insuring a high degree of uniformity. It is believed that inherent variations were in this way very largely controlled.

At this point the authors desire to express their thanks to Mr. F. G. Krauss, agronomist at this station, for cooperation in this work. All the cultural part of the investigations was done under his direction, and many valuable suggestions offered from time to time. The planning of this investigation, the securing of the analytical samples, and the presentation of the results were done by the senior author; the analytical work, for the most part, by the junior author.

Description of Analytical Samples.

Ten clumps, that is, thirty plants, selected so as to fairly represent a given plat, and which had reached, as nearly as possible, the desired stage of development, were taken from each plat at three different periods in the growth of the rice. The first series were drawn on March 27, or 44 days from the time of transplanting. This was just previous to the formation of the flowers; the second on April 21, at the time of full flowering, 25 days after the first harvest; and the third on May 17, at the time of full maturity and normal harvest, 26 days after the second harvest. These samples were carefully uprooted in such a way as to secure the entire plant, roots and all. After removing all adhering soil, by thoroughly washing the roots in running water, the samples were taken to the laboratory, where they were separated into their botanical parts. The separation of the plants from the first harvest consisted in merely severing the roots from the above-ground portion. Rice on this soil tillers greatly, and many of the culms at this time had not formed a true stalk, therefore only two parts, namely, roots and vegetative portion, were separated.

At the second harvest the plants were subdivided into four parts—roots, stems, leaves, and panicles. The roots were severed from the above-ground portion, as in the previous harvest; the leaves were detached from the stem in such a way as to leave

the leaf-sheath around the stalk attached to the stem; and the panicles were detached at their point of union with the stalk. The third, or mature, harvest was separated into five parts—roots, stems, leaves, chaff, and grain, the only differences between the separation of the second and third harvests being a division of panicles into chaff and grain.

The samples, after thorough air-drying, were weighed, finely ground, and subjected to chemical analysis. The nitrogen was determined by the ordinary Kjeldahl method, the minerals by the official methods for the analysis of inorganic plant constituents,[1] the carbohydrates by hydrolysis with hydrochloric acid, as outlined for the determination of starch in the official methods for the analysis of foods and feeding stuffs.[2] The carbohydrates, as determined by this method, include the reducing sugars, sucrose, starch, the pentoses and possibly other occasionally occurring hydrolisable carbohydrates, and were calculated for convenience to starch. It should be borne in mind, however, that the fiber, or cellulose, is not included in this determination, and the use of this designation should not be construed to mean total carbohydrates. This determination was made largely because of the known high carbohydrate content of rice, and it was thought that possibly the information obtained in this way would be of interest. A separation of the several carbohydrates in the entire series of samples would have involved analytical work far beyond the scope of this investigation. This separation, however, was undertaken with the samples from one plat, the discussion of which is reserved for the final pages of this paper.

At maturity the entire plats were harvested, and the yields of straw and grain recorded. In this bulletin, however, the discussion will be confined very largely to the analytical samples. At present, the field experiments have been carried through two crops and the third is under way. It is hoped to present the practical side of this question after the harvest of the third crop, and possibly during the present year.

At the outset it was our intention to analyze the samples from an unfertilized and each fertilized plat, but on account of the large amount of analytical work involved it has not been possible

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1 U. S. Dept. Agr., Bur. Chem. Bul. 107 (rev.), p. 21.
2 Loc. Cit., p. 53.

to complete all of these. Only four have been completed, namely an unfertilized plat, the mineral plat fertilized with phosphoric acid and potash; the nitrogen plat, which was fertilized with nitrogen only; and the complete fertilizer plat, which was fertilized with nitrogen, phosphoric acid, and potash. The primary reason for selecting these plats for analysis is found in the fact that nitrogen was the only element that materially influenced the growth of the rice. This fact manifested itself in the early development of the crop and was maintained throughout its growth. The weights of the entire plats at maturity failed to show that the application of any element, other than nitrogen, had materially affected the growth of the rice. It is unfortunate in this investigation that a soil somewhat deficient in other elements was not available.

A further reason for limiting this investigation to the four plats is found in the fact that the weather during a considerable portion of the growing period was extremely unfavorable for rice. The temperature was low for a longer time than usual and the rice consequently did not make normal growth. This fact, coupled with the almost universal practice in Hawaii of growing two crops of rice on the same land each year, suggested the advisability of studying both a spring and fall crop. Fortunately, the climatic conditions in the fall were strikingly different from the spring, and excellent weather conditions prevailed throughout the second crop.

The same procedure was followed with the fall crop as with that grown in the spring, the same fertilizers in like quantities being applied on July 16. The rice was transplanted on July 20, and the first series of samples drawn on August 26, the second on September 13, and the third on October 9. These samples represented stages of development as nearly corresponding to those from the spring crop as could be determined. At this point it is sufficient to merely call attention to the more rapid development of the rice in the fall than in the spring, ninety-five days from the time of transplanting being required for maturity in the spring, as contrasted with eighty-one days in the fall. In the table showing the gross weights at different periods it will be seen that much greater growth was also attained in the fall.

THE COMPOSITION OF RICE AS AFFECTED BY FERTILIZERS.

First Period, Spring Crop.

The results from the spring crop will be submitted first. The following table will show the water-free composition of the plant at the first harvest:

THE WATER-FREE COMPOSITION OF RICE JUST BEFORE THE FORMATION OF THE FLOWER

	CHECK PLAT			MINERAL PLAT			NITROGEN PLAT			COMPLETE FERTILIZER PLAT		
	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	1.14	2.43	2.17	1.22	2.55	2.32	1.46	2.95	2.68	1.55	3.06	2.78
Potash	1.86	2.51	2.38	1.97	2.28	2.22	2.02	2.96	2.80	2.40	3.11	2.97
Phosphoric acid	1.10	.89	.93	.97	.81	.84	1.20	.98	1.02	1.65	1.19	1.28
Lime	.44	.19	.24	.....	.....	.....	.....	.....	.....	.42	.24	.27
Magnesia	.51	.24	.29	.....	.....	.....	.....	.....	.....	.44	.19	.24
Carbohydrates	29.94	30.36	30.27	27.89	26.18	26.42	28.14	25.86	26.24	24.09	26.40	26.07

Nitrogen. The data show some unexpected and interesting facts. It is seen, for instance, that both the roots and vegetative portions from the plats fertilized with nitrogen contain a considerably higher percentage of nitrogen than from the plats not so treated. The application of minerals, in conjunction with nitrogen, also brought about a slightly greater absorption of nitrogen than the application of nitrogen alone; minerals alone increased the percentage of nitrogen somewhat, although by no means to so great an extent. Note the higher percentage of nitrogen in the dry matter of the above-ground portion of the plant, than in the roots, this being, in the case of the former, about double that of the latter.

Potash. The percentages of potash in the rice from different plats bear a similar ratio to that which was found to exist between the percentages of nitrogen, with the single exception of the mineral plat. It is significant that the application of minerals alone resulted in a slight depression, whereas the application of nitrogen alone increased the percentage of potash in the dry matter. As in the instance of nitrogen, the roots contain a smaller percentage of potash than the vegetative portion.

Phosphoric Acid. The percentages of phosphoric acid are found to have been influenced very similarly to potash, although not to such marked degree. Attention is called to the reduced percentage of phosphoric acid in the mineral plat. As contrasted with nitrogen and potash, the roots are found to contain a higher percentage of phosphoric acid than the above-ground portion.

Lime and Magnesia. Calcium and magnesium were determined in the samples from the unfertilized and complete fertilizer plats only; and the percentages were found to be very similar either when one plat was compared with the other, or calcium with magnesium. The roots contained about two times the percentage of each of these elements that was found in the vegetative portion.

Carbohydrates. The carbohydrates, as shown in the table, were also influenced by the fertilizers, the percentages in the different plats standing in inverse ratio to the percentages of nitrogen. The application of potash appears to bear no relation to the elaboration of carbohydrates up to this point.

The following table shows the composition at the flowering period:

THE WATER-FREE COMPOSITION AT THE TIME OF FULL FLOWER

	CHECK PLAT					MINERAL PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.68	.63	1.80	1.45	1.15	.66	.60	1.72	1.50	1.12
Potash	.93	1.77	1.89	.72	1.49	1.01	1.65	1.84	.68	1.43
Phosphoric acid .	.91	.74	.63	.68	.71	.78	.69	.56	.60	.64
Lime	.42	.12	.36	.12	.22	.....	.....	.....	.....	.....
Magnesia	.39	.21	.20	.27	.24	.....	.....	.....	.....	.....
Carbohydrates ..	35.09	44.08	24.00	33.01	34.86	40.08	44.87	23.25	33.24	35.64

	NITROGEN PLAT					COMPLETE FERTILIZER PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.59	.61	1.69	1.45	1.08	.55	.63	1.63	1.30	1.05
Potash	1.05	1.81	2.00	.66	1.57	1.10	1.98	2.15	.72	1.74
Phosphoric acid .	.87	.74	.66	.64	.71	.86	.69	.65	.67	.69
Lime	.....	.....	.....	.....	.....	.35	.11	.43	.12	.24
Magnesia	.....	.....	.....	.....	.....	.47	.21	.34	.27	.29
Carbohydrates ..	34.55	43.47	20.70	34.42	34.22	36.72	43.97	21.90	31.66	34.14

Nitrogen. The composition of the plant at the second harvest is materially different from that of the first, and the marked differences found in the earlier stages of growth seem to have become equalized. Much greater growth had been made at this time on those plats that were treated with nitrogenous fertilizer; but the percentage of this element in the dry matter fails to reveal a corresponding influence.

Potash. The percentages of this element have been considerably reduced also; but the influence of the fertilizers is still manifested, although to a lesser degree than in the first period. Again the application of nitrogen alone enabled the plant to absorb a greater percentage of potash than when it was unfertilized, and if the minerals were applied, in addition to nitrogen, a still greater percentage of potash was taken up. The application of minerals alone had but little effect.

Phosphoric Acid. At this harvest the fertilizers seem to have exerted no material influence on the percentage of phosphoric acid in the dry matter.

Lime and Magnesia. The percentages of calcium and magnesium in the plants from the unfertilized and complete fertilizer plats were found to be practically the same.

Carbohydrates. The percentages of hydrolisable carbohydrates had considerably increased since the first harvest, and bear a somewhat inverse ratio to the percentages of nitrogen. This period represents a time of rapid growth and a consequent great elaboration of carbohydrates. The total weight of the plant at this period shows a development of about four times as much dry matter as had been formed at the first harvest. Hence, we should expect a smaller percentage of nitrogen and minerals, and a corresponding increase in carbohydrates. At this harvest the plant was in the midst of its most vital activity —the process of seed formation. It was storing up reserve materials and transforming carbohydrates into true starch. The analytical data show some interesting results.

Third Period, Mature Harvest, Spring Crop.

The following table shows the composition of the different plats at maturity:

THE WATER-FREE COMPOSITION AT MATURITY

	CHECK PLAT							MINERAL PLAT						
	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per ent*	*Per cent*	*Per cent*
Nitrogen	.63	.50	.86	.52	1.36	.58	.90	.63	.46	.86	.49	1.36	.57	.88
Potash	.58	2.18	1.30	.96	.39	1.69	1.10	.54	2.31	1.32	.98	.44	1.78	1.18
Phosphoric acid .	.76	.26	.28	.43	.98	.30	.61	.67	.23	.23	.30	.92	.24	.53
Lime	.70	.10	.69	.15	.02	.24	.19	.....	.....	.....	.....	.....	.....	.....
Magnesia	.83	.08	.21	.26	.27	.13	.24	.....	.....	.....	.....	.....	.....	.....
Carbohydrates ..	34.55	29.61	18.53	18.02	79.66	24.36	47.32	35.74	28.64	22.07	17.53	80.97	24.61	47.18

	NITROGEN PLAT							COMPLETE FERTILIZER PLAT						
	Roots	Stems	Leaves	Chaff.	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.62	.44	.81	.56	1.31	.60	.85	.52	.40	.67	.47	1.24	.49	.78
Potash	.64	2.32	1.17	1.00	.42	1.74	1.15	.64	2.68	1.22	.93	.41	1.89	1.24
Phosphoric acid .	.68	.25	.23	.41	.89	.27	.54	.77	.20	.25	.32	.92	.24	.53
Lime	.....	.....	.....	.....	.....	.....	.....	.65	.10	.61	.17	.02	.27	.20
Magnesia	.....	.....	.....	.....	.....	.....	.....	.80	.10	.23	.21	.25	.16	.24
Carbohydrates ..	35.52	28.60	21.16	16.49	83.52	24.15	47.75	31.12	25.42	19.04	16.95	83.80	21.82	46.20

Nitrogen. As was found at the second harvest, the fertilizers appear to have exerted little or no influence on the percentage of nitrogen in the mature plant. There are certain irregularities in the same parts of the plants from different plats, but when we consider either the straw, which is here used to include stems, leaves, and chaff, or the entire plant, the percentages of nitrogen are very similar, with the exception of the complete plat, which contained a slightly smaller percentage of nitrogen. It is somewhat difficult to explain this variation.

Potash. The percentage of potash in the mature plant is found to have been somewhat modified by fertilization. In the total plant from the different plats, for instance, the percentage of potash was as follows: Check plat 1.10 per cent, mineral plat 1.18 per cent, nitrogen plat 1.15 per cent, and complete fertilizer plat 1.24 per cent. Thus it is shown that the application of potash brought about an increase in the percentage of potash in the dry matter, either when the complete fertilizer plat is compared with the nitrogen plat, or the mineral plat with the check.

Phosphoric Acid. The percentages of phosphoric acid contained in the several parts of the mature plant do not appear to have been influenced by the fertilizers. The percentage in the whole plant was only slightly less than at the second harvest, whereas the percentage in the straw had been reduced by more than half.

Lime and Magnesia. The percentages of these substances in the mature plant are nearly equal, there being only .04 per cent more magnesia than lime. The percentages in the above-ground parts, however, are decidedly different, the leaves having been found to contain a much larger percentage of lime than the other parts, whereas the percentage of magnesia is about equal in leaves, chaff, and grain. Lime occurs in the grain to the extent of .02 per cent as contrasted with .24 per cent magnesia.

Carbohydrates. The carbohydrate data, while not altogether concordant, show that the process, already begun at the second harvest, was continued with acceleration. There is a general lowering of the percentage of carbohydrates in all the plant organs, except grain, where it is stored up. The fertilizers seem to have had little influence on this process, except in the grain

from the plats fertilized with nitrogen, which contain about 3 per cent more carbohydrates than from the other plats.

As already stated, the weather conditions during a large part of the growth of the spring crop were very unfavorable. Rice throughout the islands made unusually slow growth and small yields were obtained generally. It should be borne in mind, however, that there were no variations in moisture in the two respective crops, and therefore, the differences in the behavior of the plant may be safely attributed to temperature. The results from the fall crop will now be given.

First Period, Fall Crop.

The following table represents the composition of the plant at the first harvest from the fall-grown crop:

WATER-FREE COMPOSITION AT THE FIRST HARVEST

	CHECK PLAT			MINERAL PLAT			NITROGEN PLAT			COMPLETE FERTILIZER PLAT		
	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant	Roots	Vegetative Portion	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	1.07	2.16	1.99	1.00	2.10	1.95	1.28	2.30	2.17	1.48	2.72	2.50
Potash	2.06	3.12	2.96	1.97	3.08	2.93	1.90	3.25	3.07	2.50	3.51	3.33
Phosphoric acid	1.12	.92	.95	1.21	.83	.88	1.23	.84	.89	1.41	.90	.99
Carbohydrates	29.73	26.56	27.06	29.60	26.61	27.02	27.73	24.07	24.54	29.11	22.23	23.44

Nitrogen. The percentage of nitrogen in the dry matter was materially influenced by the application of this element, although the application of a complete fertilizer increased the percentage of nitrogen considerably more than the application of nitrogen alone. Minerals without nitrogen had but little effect.

Potash. The application of a complete fertilizer materially increased the percentage of potash in the dry matter. The application of minerals or nitrogen alone had but little influence on the percentage of potash during this period.

Phosphoric Acid. The absorption of phosphoric acid appears to have been influenced but slightly, if indeed at all, by fertilization.

Carbohydrates. The percentages of hydrolisable carbohydrates are found to stand in inverse proportions to the percentages of nitrogen in the dry matter.

Second Period, Fall Crop.

The following table sets forth the analytical data for the second period of the fall crop:

WATER-FREE COMPOSITION AT THE SECOND HARVEST

	CHECK PLAT					MINERAL PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.75	.65	1.72	1.28	1.01	.81	.74	1.46	1.32	1.02
Potash	1.18	2.02	2.33	.73	1.77	1.28	2.14	2.21	.77	1.81
Phosphoric acid .	1.02	.69	.49	.53	.64	.95	.68	.47	.59	.63
Carbohydrates ..	36.04	36.88	19.78	30.00	31.73	35.70	36.06	19.84	30.60	31.33

	NITROGEN PLAT					COMPLETE FERTILIZER PLAT				
	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.90	.89	1.64	1.41	1.19	.98	.81	1.63	1.38	1.15
Potash	1.50	2.45	2.12	.75	1.93	1.52	2.68	2.33	.79	2.12
Phosphoric acid .	1.06	.73	.41	.57	.63	1.23	.76	.45	.57	.67
Carbohydrates ..	32.24	29.59	18.43	31.41	27.40	33.40	30.80	18.82	29.52	27.64

Nitrogen. The previous fertilization with nitrogen exerted a direct influence on the composition of the plant at this harvest, the influence being most marked in the roots, stems, and panicles. As compared with the check plat the percentage of nitrogen in the total plant was increased by fertilization, as follows: .18 per cent by nitrogen only and .14 per cent by the complete fertilizer. Minerals alone exerted no influence.

Potash. The influence of the fertilizers on the percentages of potash absorbed is even more marked at this harvest than at the first. From all the fertilized plats there was a higher percentage of potash in the roots, stems, and total plant than from the check plat. This was much more marked in the instance of the complete plat, although nitrogen alone exerted an appreciable influence on this element. In the total plant, for instance, there is 1.77 per cent in the check plat, 1.81 per cent in the mineral plat, 1.93 per cent in the nitrogen plat, and 2.12 per cent in the complete fertilizer plat.

Phosphoric Acid. The use of fertilizers seems to have exerted but little influence on the percentage of phosphoric acid in the dry matter.

Carbohydrates. As was found in the first period, the hydrolisable carbohydrates stand in inverse proportion to the nitrogen assimilated. In the total plant, for instance, the nitrogen was as follows: 1.01 per cent in the check plat, 1.02 per cent in the mineral plat, 1.19 per cent in the nitrogen plat, and 1.15 per cent in the complete fertilizer plat; and carbohydrates in the corresponding plats, 31.73 per cent, 31.33 per cent, 27.40 per cent, and 27.64 per cent respectively.

Third or Mature Harvest, Fall Crop.

The composition of the plant at maturity was as follows:

THE WATER-FREE COMPOSITION AT MATURITY

	CHECK PLAT							MINERAL PLAT						
	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.76	.42	.61	.39	1.09	.46	.74	.72	.47	.65	.49	1.25	.52	.82
Potash	.71	2.44	1.26	1.02	.42	1.87	1.19	.70	2.20	1.18	.98	.46	1.69	1.16
Phosphoric acid .	1.15	.17	.17	.29	.86	.19	.52	.89	.18	.17	.31	.84	.21	.49
Carbohydrates ..	37.64	22.52	17.75	15.90	80.45	19.99	47.00	34.52	25.21	19.44	21.21	79.79	22.92	46.09

	NITROGEN PLAT							COMPLETE FERTILIZER PLAT						
	Roots	Stems	Leaves	Chaff.	Grain	Straw	Total Plant	Roots	Stems	Leaves	Chaff	Grain	Straw	Total Plant
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Nitrogen	.84	.38	.62	.43	1.36	.45	.86	.71	.43	.56	.51	1.22	.48	.81
Potash	.73	2.62	1.33	1.06	.46	1.94	1.25	.94	3.06	1.29	1.12	.39	2.16	1.36
Phosphoric acid .	1.14	.14	.18	.26	.87	.18	.53	1.07	.15	.16	.32	.83	.19	.50
Carbohydrates ..	26.50	19.83	18.17	16.90	79.45	18.75	45.47	27.37	20.83	18.49	16.86	80.29	19.33	45.53

Nitrogen. The percentages of nitrogen in the different plats at the third harvest appear to have become very largely equalized. The straw contains practically the same percentage of nitrogen on all the plats, but the grain on each of the fertilized plats contained more nitrogen than on the check plat. Even the mineral plat shows this effect.

Potash. The percentages of potash in the mature plant show that the composition of the rice plant may be materially influenced by fertilizers. We find, for instance, that the potash in the straw varied according to fertilization as follows: The unfertilized plat 1.78 per cent, the mineral plat 1.61 per cent, the nitrogen plat 1.85 per cent, and the complete fertilizer plat 2.08 per cent. In the whole plant similar differences occurred.

Phosphoric Acid. The mature plant shows no appreciable differences in the percentages of phosphoric acid.

Carbohydrates. The percentages of carbohydrates show a fairly concordant agreement in all plats at maturity and only small variation occurred.

The Influence of Season on the Composition of Rice.

The temperature in Honolulu throughout the rice-growing months is usually very uniform, although somewhat warmer in the summer and fall than in the spring. During the first two months of the spring crop, however, the average temperature was lower than is usual for these months, whereas the temperature during the growth of the fall crop was normal.

The following table, taken from the reports of the U. S. Weather Bureau at Honolulu, shows the maximum, average, and minimum temperatures for each period of the two crops:

TEMPERATURE RECORDS.

	Spring Crop.			Fall Crop.		
	First period.	Second period.	Third period.	First period.	Second period.	Third period.
	° F.	° F.	° F.	° F.	° F.	° F.
Maximum ...	78	80	82	83	84	83
Average.....	70.5	71	73	76.5	76.5	77
Minimum ...	56	62	67	68	68	70

These records show that the temperature was considerably lower during the growth of the spring crop, either from the standpoint of maximum, average, or minimum temperatures.

With the view of bringing out the difference in composition due to temperature, the following table, taken from the complete fertilizer plat, is brought together, which affords a comparison of the composition of the total plant when grown under the different seasonal conditions.

THE COMPOSITION OF SPRING AND FALL CROPS, TOTAL PLANT.

	First Period		Second Period.		Third Period.	
	Spring crop.	Fall crop.	Spring crop.	Fall crop.	Spring crop.	Fall crop.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Nitrogen	2.78	2.50	1.05	1.15	.78	.81
Potash	2.97	3.33	1.74	2.12	1.24	1.36
Phosphoric acid	1.28	.99	.69	.67	.53	.50
Carbohydrates	26.07	23.44	34.14	27.64	46.20	45.53

These figures show that while the composition of the mature crop was not greatly influenced by season, at earlier periods it was markedly different. Considerably more nitrogen and phosphoric acid were absorbed for a given amount of dry matter in the spring crop, at the first harvest, than at the corresponding stage of development of the fall crop. At the second harvest these had become nearly equalized and at maturity were practically the same. With potash a somewhat different condition is found. The percentage of potash is consistently greater in the fall crop at every period than was found in the spring crop, although not greatly different at maturity. Considering the hydrolisable carbohydrates, the spring crop contained a much higher percentage at the first and second harvests than the fall crop. At maturity only a small difference is found, although there was a somewhat higher percentage in the spring crop than in the fall. It seems justifiable to conclude from the data, therefore, that seasonal variations are of importance, and must be considered in studying the composition of the rice plant.

General Discussion of the Results from Both Spring and Fall Crops.

Summing up the data for the two crops, it has been shown that the use of nitrogenous fertilizer produced a marked increase in the percentage of nitrogen in the dry matter during the early development of the plant. This increase, however, was not manifested throughout the life history of the plant, but extended only through the first period in the spring crop, whereas, in the fall crop a considerable increase in the percentage of nitrogen absorbed was still manifested at the second period. At maturity only slight differences were found. In both crops fertilization with minerals, in conjunction with nitrogen, brought about increased absorption of potash throughout the entire growth of the rice. Minerals alone tended to reduce the percentage of potash in the dry matter. The percentage of phosphoric acid in the dry matter was slightly increased by the fertilizers during the first period in both crops, being more marked in the spring crop. The second and third harvests, however, failed to reveal a similar influence on the composition.

The rice plant, in common with other cereals, contains a high percentage of nitrogen, potash, and phosphoric acid in its early growth, and these are gradually reduced until the time of maturity. The elaboration of carbohydrates proceeds at an increasing rate throughout the growth of the plant. It is found, for instance, that the total plant from the complete plat of the fall crop contained at the three periods the following percentages of these elements:

THE COMPOSITION OF THE RICE PLANT AT THREE DIFFERENT PERIODS OF GROWTH.

	Nitrogen.	Potash.	Phosphoric Acid.	Carbohydrates.
	Per cent.	Per cent.	Per cent.	Per cent.
First period	2.50	3.33	.99	23.44
Second period	1.15	2.12	.67	27.64
Third period	.81	1.36	.50	45.53

Calcium and magnesium, while determined in the spring crop only, show a slight concentration at the first period as compared with the percentages at later periods. In the mature plant the calcium is stored very largely in the leaves, while magnesium migrates to the grain.

THE ABSORPTION OF NUTRIENTS BY THE RICE PLANT.

As already stated, one of the objects in undertaking this investigation was to determine at what period in the growth of the rice plant the main portion of the several elements is taken up. The data and discussion presented in the preceding pages demand further development in order to throw more light on this point. It has been decided to present the complete data for the fall crop only, since this crop grew under more nearly normal seasonal conditions.

Dry Matter Formed. First, taking up the weights in pounds of dry matter per acre at the three periods, then the corresponding data for the several elements will be given. The following table shows the pounds per acre of dry matter in the several parts of the plant at the three periods:

AMOUNT PER ACRE OF DRY MATTER AT THE THREE PERIODS

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Totsl Plant
	Lbs,	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat.....	253	1382	1635	253	1686	723	660	3322	208	1616	659	639	2411	5533
Mineral Plat.....	203	1280	1483	255	1765	776	732	3528	276	1658	790	612	2199	5535
Nitrogen Plat.....	335	2256	2591	363	2695	1434	1294	5786	347	2362	1222	982	3783	8696
Complete Fertilizer Plat..	430	2009	2439	385	2488	1380	1094	5347	313	2345	1235	996	3610	8499

Considering the weights at the three harvests, it is readily seen that the rice made a very much greater growth on the plats treated with nitrogenous fertilizer. The effects of the treatment could be seen in the early stages of growth and were manifested throughout. Minerals with or without nitrogen, as already stated, had but little effect.

Nitrogen. The following table will show the nitrogen as found in the different parts of the plant at the three harvests:

AMOUNT PER ACRE OF NITROGEN ABSORBED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat.....	2.7	29.9	32.6	1.9	10.9	12.4	8.4	33.6	1.6	6.8	4.0	2.5	26.2	41.1
Mineral Plat.....	2.0	26.9	28.9	2.1	13.0	11.3	9.6	36.0	1.9	7.7	5.2	3.0	27.6	45.4
Nitrogen Plat.....	4.3	52.0	56.3	3.3	23.9	23.5	18.3	69.0	2.9	8.9	7.5	4.2	51.4	74.9
Complete Fertilizer Plat..	6.4	54.6	61.0	3.8	20.1	22.4	15.1	61.4	2.2	10.1	6.9	5.1	44.1	68.4

Considering the greatest amount of an element contained in the plant at any one time in its development as 100, the data from the first harvest show that the plant had taken up 89.2 per cent of its nitrogen in the case of the complete plat, 75.2 per cent on the nitrogen plat, 63.6 per cent on the mineral plat, and 79.3 per cent on the check plat; at the second harvest it had absorbed 89.6 per cent on the complete plat, 92.1 per cent on the nitrogen plat, 79.3 per cent on the mineral plat, and 81.7 per cent on the check plat. Therefore, it appears that, from the standpoint of the needs of the plant, the time to fertilize with nitrogen is before or during the early growth of the crop. By early application of nitrogen, not only is the nitrogen absorbed early, but much more vigorous growth and tillering brought about. Certainly the application of nitrogen at a time when the plant has already absorbed four-fifths of its nitrogen could not produce the greatest increase in growth. The rice plant, in common with other cereals, needs readily available nitrogen in abundance during its early development.

The data in the previous table bring out the facts of transmigration of nitrogen also. The absolute amount of nitrogen in the roots, for instance, gradually decreased from the first to the third harvest. It is also found that the grain at maturity contained about 60 per cent. of the nitrogen in the total plant, and that of this a large part had been derived from the stems and leaves, which, at the second harvest, were found to contain considerably more of this element than at maturity.

Potash. The potash absorbed at the three harvests is represented in the following table:

AMOUNT PER ACRE OF POTASH ABSORBED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	5.2	43.1	48.3	3.0	34.1	16.9	4.8	58.8	1.5	39.4	8.3	6.5	10.0	65.7
Mineral Plat	4.0	39.4	43.4	3.2	37.8	17.2	5.6	63.8	1.9	36.5	9.3	6.1	10.2	64.0
Nitrogen Plat	6.3	73.3	79.6	5.5	65.9	30.4	9.7	111.5	2.5	61.9	16.2	10.5	17.3	108.4
Complete Fertilizer Plat.	10.8	70.4	81.2	5.8	66.7	32.2	8.7	113.4	2.9	71.8	15.9	11.2	14.1	115.9

The above table shows that the rice from the complete plat, at the first harvest, had absorbed 70.1 per cent of its maximum potash, from the nitrogen plat 71.4 per cent, from the mineral plat 67.9 per cent, and from the chock plat 73.5 per cent. At the second harvest it had absorbed on the complete plat 97.8 per cent, on the nitrogen plat 100 per cent, on the mineral plat 99.7 per cent, and on the check plat 89.5 per cent of its total potash. The nitrogen plat seems to be an exception, in that it actually contained more potash at the second harvest than at maturity, there being only 97.2 per cent as much at maturity as at the previous harvest. Whether this apparent loss is due to analytical error,[1] it cannot be definitely stated. It is so slight, however, as to be of no great importance. The potash in the roots at the first harvest was gradually reduced throughout the subsequent growth of the plant, and at maturity the main portion of potash is stored in the stems.

Phosphoric Acid. The next table will show the amounts of phosphoric acid absorbed at the different harvests.

At the first harvest the complete plat had absorbed 57.6 per cent of its maximum phosphoric acid, the nitrogen plat 50.8 per cent, the mineral plat 47.9 per cent and the check plat 53.8 per cent, while at the second harvest the check plat contained 73.7 per cent, the mineral plat 81.7 per cent, the nitrogen plat 81.4 per cent, and the complete plat 85.7 per cent. The phosphoric acid in the roots at the first harvest was gradually reduced throughout the subsequent development of the plant, and during the period of seed formation a marked rearrangement takes place, resulting in the stems and leaves giving up practically all of their phosphoric acid, which is largely stored in the grain.

The foregoing data, therefore, reveal no scientific basis for the application of fertilizers to rice when it is two-thirds grown. By the time the plant has reached this period fully three-fourths of the total nitrogen and phosphoric acid and nine-tenths of the potash have already entered the plant; and hence the application of fertilizer at this time cannot possibly be of the greatest

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1 Liebscher (*Jour. Landw.*, 35 (1887), p. 335), has pointed out that some plants sustain loss through the withering and decay of lower leaves, with rice grown in submerged culture, we believe such loss to be unimportant.

AMOUNT PER ACRE OF PHOSPHORIC ACID ABSORBED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	2.8	12.7	15.5	2.6	11.6	3.5	3.5	21.2	2.5	2.7	1.1	1.9	20.6	28.8
Mineral Plat	2.5	10.6	13.1	2.4	12.0	3.6	4.3	22.3	2.5	3.0	1.4	1.9	18.5	27.3
Nitrogen Plat	4.1	18.8	22.9	3.9	19.6	5.8	7.4	36.7	4.0	3.3	2.2	2.6	33.0	45.1
Complete Fertilizer Plat.	6.1	18.1	24.2	4.8	18.8	6.2	6.2	36.0	3.3	3.6	1.9	3.2	30.9	42.0

value to the immediate crop, and is sure to result in a loss of plant food.

Hydrolisable carbohydrates. The following table will show the amounts of hydrolisable carbohydrates in the plant at its several stages of growth.

There is a rapid increase in carbohydrates from the first harvest till the last. At maturity there is less of these carbohydrates in the stems and leaves than at the second harvest. In addition to the transfer of these substances into the grain an enormous elaboration of true starch also takes place during the ripening process. This carbohydrate is, of course, very largely deposited in the grain. A fact worthy of notice in this connection is that there seems to be no relation between the absolute amounts of hydrolisable carbohydrates in the plant and the use of potash fertilizer. It is well known, however, that potash in some way not thoroughly understood is associated with the formation of the carbohydrates and their transference, and since in this soil there already existed a maximum of available potash it should not be expected that the application of this substance would produce appreciable effects on the amounts of carbohydrates in the plant.

Excessive Absorption. Numerous investigations have shown that the composition of mature plants may be very different, depending on the moisture supply, the amount of available plant food, the type of soil, seasonal variations, etc. Sugar beets grown on alkali soils are known to contain abnormal percentages of the alkalis present,[1] and this crop has even been grown on such soils as a means of effectively reducing the amounts of poisonous alkalis in the soil. Wheeler and Hartwell[2] have shown that a number of crops, when grown on certain soils and fertilized with sodium salts, take up less potash and more soda than when unfertilized. Voorhees and Lipman[3] have recently pointed out that the application of phosphates and potassium salts had the effect of reducing the percentage of nitrogen in corn, etc. They also found that the application of nitrogen from various sources, in addition to the minerals, tend-

1 California Sta. Bul. 128.
2 Rhode Island Sta. Rpt. 1906, p. 284.
3 New Jersey Stas. Bul. 221.

AMOUNT PER ACRE OF CARBOHYDRATES ELABORATED BY THE RICE PLANT

	FIRST PERIOD			SECOND PERIOD					THIRD PERIOD					
	Roots	Vegetative Portion	Total Plant	Roots	Stems	Leaves	Panicles	Total Plant	Roots	Stems	Leaves	Chaff.	Grain	Total Plant
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Check Plat	75.1	367.4	442.5	91.2	621.7	143.1	198.1	1054.1	78.5	363.9	116.9	101.6	1939.5	2600.4
Mineral Plat	60.0	340.8	400.8	91.1	636.3	154.0	224.1	1105.5	95.1	418.1	153.6	129.9	1754.4	2551.1
Nitrogen Plat	92.9	542.8	635.7	117.0	797.5	264.3	406.6	1585.4	92.0	468.5	221.9	166.0	3005.2	3953.6
Complete Fertilizer Plat.	125.3	446.5	571.8	128.7	766.2	259.6	323.1	1477.6	85.4	488.6	228.4	167.9	2898.8	3869.0

ed to bring about a higher percentage of nitrogen in the crop grown than was taken up when minerals alone were applied. Snyder[1] has shown that nitrogen fertilization may affect not only the total percentage of nitrogen in wheat, but he found this treatment to exert an influence on the form which the nitrogen assumed in the grain. Wiley[2] has shown that environment exercises a considerable influence on the composition of sugar beets, and recently Straughn and Church have brought out some interesting facts regarding variation in the sugar content of sweet corn,[3] due to climate, etc. Wiley[4] and McDonnell[5] show that the composition of rice grown in different localities varies considerably although sufficient data are not given to enable the reader to determine the causal factors.

The taking up of an increased percentage of an element per unit of dry matter formed under the influence of additional available plant food may be looked upon as excessive absorption. that is, more potash or nitrogen, as the case may be, is absorbed than is necessary for the elaboration of a given amount of dry matter. In fertilizer studies this fact is not only of scientific interest, but has a decided practical bearing. If an important function of fertilizers is to add necessary plant food to the soil. in the economic use of manures, it is important that every source of loss or waste be avoided.

The data already submitted are of interest in this connection. It has been pointed out that nitrogen is the only element that is materially deficient in the soil used in our experiment. This fact is brought out more strikingly by referring to the acre yields at maturity, which were calculated from the weights of the entire plats. These for both the spring and fall crops are submitted in the following table:

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1 Minnesota Sta. Bul. 102.
2 U. S. Dpt. Agr., Bur. Chem. Buls. 95, 96.
3 U. S. Dpt. Agr., Bur. Chem. Bul. 127.
4 U. S. Dpt. Agr., Div. Chem. Bul. 45.
5 South Carolina Sta. Bul. 59.

AMOUNT PER ACRE OF AIR-DRIED GRAIN AND STRAW.

	Spring crop.			Fall crop.		
	Grain.	Straw.	Total.	Grain.	Straw.	Total.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Check Plat	944	1218	2162	2366	2525	4891
Mineral plat	1101	1478	2575	2174	2582	4756
Nitrogen plat	1683	2267	3950	3440	3816	7256
Complete fertilizer plat	1822	2578	4400	3354	3767	7121

The yields show that the minerals exerted a small influence on the gross weights of the spring crop. The fall crop grown on the same plats, and fertilized exactly as in the spring, however, yielded a smaller harvest where the minerals were applied, either when mineral fertilization is compared with no fertilization, or minerals and nitrogen with nitrogen alone. The differences in this particular are small in each crop, however, and are very likely within the range of experimental error. By referring to Table No. I, this soil is shown to contain a relatively high percentage of phosphoric acid, although we are quite aware that the deficiencies of a soil for a specific crop cannot with certainty be determined by chemical analysis. It has already been found that this soil contains .10 per cent phosphoric acid soluble in N|5 hydrochloric acid, and the potash in the coastwise soils of Hawaii is known to be quite soluble. We therefore feel justified in concluding that this soil contains an abundance of available minerals, and hence the application of minerals resulted in supplying to the rice an excess of available potash and phosphoric acid. What was the effect on the composition of the plant?

The percentage of phosphoric acid in the dry matter of the mature plant was found to have been unchanged regardless of the use of fertilizers, neither minerals nor nitrogen having produced any effect. The percentage of phosphoric acid absorbed during the first period was slightly increased by the application of phosphoric acid, only, however, when applied with nitrogen. In the case of potash, mineral fertilizers with nitrogen increased the percentage of potash in the plant throughout its growth. Minerals alone, on the other hand, did not so affect the plant. From these facts it seems reasonable to conclude that the rice

plant in the presence of an excess of potash may absorb an excess of potash. But with phosphoric acid we cannot be sure of a similar absorption. It seems most likely, however, that this soil already contained such a large amount of available phosphate as compared with that applied, that only a very temporary concentration was brought about, and that the rice on all plats alike had access to excessive amounts of phosphoric acid. Therefore, in this particular the data cannot be contrasted. All that can be said on this point is that analyses of rice, either straw or grain, grown on soil elsewhere[1] show an almost uniformly smaller percentage of phosphoric acid than we have found in Hawaii. The percentage of potash in the grain is also greater than has been found elsewhere.

We find that during the early stages of growth the rice on the plats fertilized with nitrogen took up nitrogen in excess over and above the maximum amount required for the production of a given amount of dry matter; and that in succeeding periods of its growth this nitrogen absorbed in excess was in part drawn on rather than that in the soil. For instance, during the first period one pound of nitrogen was absorbed for each 50 pounds of dry matter in the check plat, 51 pounds in the mineral plat, 44 pounds in the nitrogen plat, and 40 pounds in the complete fertilizer plat. At the second harvest one pound of nitrogen had been absorbed for each 99 pounds of dry matter in the check plat, 98 pounds in the mineral plat, 84 pounds in the nitrogen plat, and 83 pounds in the complete fertilizer plat; and at the third harvest one pound of nitrogen was sufficient for the formation of the following amounts of dry matter: Check plat 135 pounds, mineral plat 122, nitrogen plat 116, and complete fertilizer plat 123. Thus we see that one pound of nitrogen absorbed, was sufficient for the formation of more pounds of dry matter at all stages of growth on the check than on the plats treated with nitrogen. At the final harvest, however, this difference had become more nearly equalized.

If we consider, on the one hand, the growth during the third period only, which represents a time of rapid development and increase in weight, and the pounds of nitrogen absorbed during

[1] Texas Sta. Bul. 82; Col. of Agr. Tokyo Imp. Univ., Vol. 1, No. 12; South Carolina Sta. Bul. 59.

this period, on the other, we find that the plant when previously fertilized with nitrogen apparently drew in part on the nitrogen already stored up in the plant, rather than obtaining its nitrogen wholly from the soil. For instance, during this period one pound of nitrogen entered the plant from the soil for every 295 pounds of dry matter produced on the check plat, 213 pounds on the mineral plat, 493 pounds on the nitrogen plat, and 450 pounds on the complete plat.

The Loss of Elements by Plants During the Ripening Stage. In recent years it has been pointed out that many plants contain a greater quantity of a given element at maturity than at some previous stage. In general, cereals have been found to contain their maximum of certain elements at the flowering stage, and in certain instances the absolute amounts rapidly decrease after passing through this stage. Wilfarth, Romer, and Wimmer[1] pointed out that both barley and wheat contained very considerably less potash and nitrogen at maturity than previously, and these authors attempt to explain this decrease on the assumption that these elements, after performing their physiological functions, are returned through the roots to the soil. Numerous investigations bearing on this point might be cited. Recently LeClerc and Breazeale[2] have investigated this subject, using a number of different crops, rice included, and from their work the conclusion is drawn that the loss of mineral constituents and nitrogen, which some plants suffer during the ripening process, cannot be explained on the basis of a backward and downward transmigration within the plant. They found, for instance, that the lower nodes of the mature wheat stalk contain less potash than the nodes higher up; and also that the roots contained rather less of this element at maturity than previously. On the other hand, when wheat, barley, rice, etc., are subjected to a leaching process, similar to natural rains and dews, a decided loss is sustained. From these findings they conclude that such losses in nature are due to the influences of rains and dews, which wash off and leach away the elements that are brought to the surface through transpiration, etc.

The data already submitted are instructive in this connec-

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1 Landw. Vers. Stat., 63 (1905), No. 1-2, pp. 1-70.
2 U. S. Dpt. Agr., Yearbook 1908, p. 389.

tion. The rice from none of the plats, with the single exception of the nitrogen plat, and then only so slight as to be negligible, suffered any loss of minerals or nitrogen. It is true the plant had absorbed practically all its potash at the flowering period, but we find no evidence of a return to the soil. The percentages of nitrogen, potash, and phosphoric acid in the roots steadily decreased from the first period to maturity, which, as pointed out by LeClerc and Breazeale, would at least indicate the absence of a physiological process of excretion from root surfaces. The only abnormal weather condition to which the crop was subjected was the almost total absence of rain during the latter half of the growth. In addition, those who are familiar with weather conditions in Honolulu appreciate the fact that dews are exceedingly rare. It is the consensus of opinion of those who observed the weather during the time represented as the third priod in the growth of this rice, that not enough water fell or collected on this rice at any one time to trickle down the stalks. Hence there could have been no leaching, thus bringing about loss to the plant. From these facts it seems that rice grown under normal conditions does not return its elements through the roots to the soil; and, judging from the investigation cited, it seems most likely that leaching may be the chief means of loss to plants in this connection.

A STUDY OF THE CARBOHYDRATES IN THE RICE PLANT.

During the course of the work recorded in the preceding pages some parts of the rice plant were found to contain large amounts of the lower carbohydrates, and since various other carbohydrates, which undergo hydrolysis with boiling acids, are known to be present in mature cereals, it occurred to us that a study of the formation of these bodies might not be without interest. Accordingly, the samples from one plat were set aside for this work. The principal idea in this connection was, therefore, to gain further light on the various substances that are previously reported in this bulletin as carbohydrates. In addition, the cellulose (fibre) is also given. Attention is called to the fairly close agreement between the total of the various carbohydrates, as determined by the methods employed and "carbohy-

drates" previously given, which as already stated, were calculated to starch from the one determination, by the method of hydrolysis with boiling hydrochloric acid. The latter determination was not made with the samples reported herewith, however, and since certain variations were found in the plats already presented, it could not be expected that the sum of the carbohydrates, as determined separately, would be exactly equal to the lump determination, "carbohydrates", in any other plat. The more especially is this fact forced upon us when it is considered that the hydrolisable carbohydrates were previously calculated to starch, which is not only an arbitrary expedient, but cannot be looked upon as being mathematically correct, since, in hydrolysis different carbohydrates take up varying amounts of water and undergo changes of unequal magnitude. The agreement in the two instances is, therefore, as close as could be reasonably expected.

The carbohydrate groups which have been separated are as follows: Reducing sugars, sucrose, starch, pentoses, and cellulose. For the determination of reducing sugars the finely-ground samples were steeped with distilled water for a period of two hours, after which they were made up to a definite volume, filtered, and an aliquot taken for the regular Fehling solution reduction. Sucrose was determined by the process of inversion with invertase from yeast, and was likewise made up to a volume, filtered, and an aliquot taken for Fehling solution reduction. Starch was separated by first boiling the samples with water and then hydrolising with diastase from malt extract, completing to volume and filtering, after which an aliquot was boiled with hydrochloric acid to insure complete conversion into reducing sugars. After neutralization with potassium hydrate, the solution was allowed to act on Fehling solution. To all solutions alike, a small quantity of toluene was added to prevent alcoholic fermentation. In every instance the reduced copper was weighed as cuprous oxide. The pentoses were determined by the method of the Association of Official Agricultural Chemists, the phloroglucid being calculated to pentose sugars. The cellulose determinations were made according to the usual method for fiber determinations in feeds, etc.

First period. The following table sets forth the analytical results for the first period:

THE WATER-FREE CARBOHYDRATES AT THE FIRST PERIOD.

	Roots.	Vegetative portion.	Total plant.
	Per cent.	Per cent.	Per cent.
Reducing sugars	3.38	7.12	6.34
Sucrose	Trace	.00	Trace
Starch	8.51	8.13	8.21
Pentoses	22.09	12.02	14.09
Cellulose	26.02	19.97	21.20

Without discussing the data at length, it is sufficient to merely call attention to the rather large percentage of reducing sugars, especially in the above-ground portion of the plant, at this harvest. Sucrose was practically absent from the plant at this time, and starch occurred in almost equal percentages in all parts of the plant. There was a large percentage of pentose sugars, especially in the roots, being about twice as much in this part of the plant as in the vegetative portion. Cellulose also occurred in large quantities in the roots.

Second period. The following table shows the percentages of these substances at the flowering period:

THE WATER-FREE CARBOHYDRATES AT THE SECOND PERIOD.

	Roots.	Stems.	Leaves.	Panicles.	Total Plant.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Reducing sugars	5.23	6.53	2.92	.26	4.17
Sucrose	3.09	10.38	1.44	.00	5.01
Starch	11.15	13.44	4.00	9.54	9.63
Pentoses	19.25	14.31	16.51	20.02	17.18
Cellulose	23.74	22.57	24.29	33.18	28.30

The reducing sugars, as compared with the first period, were found to have been slightly increased in the roots and somewhat reduced in the above-ground portion, and were greatest in the stems. The panicles contained only .26 per cent of reducing sugars. The percentages of sucrose are indeed surprising, especially in the stems, where it occurred to the extent of 10.38 per

cent of the dry matter. In the panicles not a trace was detected. Starch had increased since the first harvest and was greatest in the stems, followed in order by the roots, panicles, and leaves. The percentages of pentoses were large in all parts of the plant, were greater than the percentages of starch in every part, and in the total plant almost double that of the latter. The percentage of fiber was still higher and varied somewhat according to the variations in pentose-forming bodies. In the total plant at this harvest cellulose constituted about one-fourth of its weight. The data are very interesting throughout and give an indication of the changes that take place as the plant proceeds in its development.

Third period. The next table shows the carbohydrates at maturity.

THE WATER-FREE CARBOHYDRATES[1] AT THE THIRD PERIOD.

	Roots.	Stems.	Leaves.	Chaff.	Grain.	Total Plant.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Reducing sugars	3.48	3.13	1.31	.54	.00	1.43
Sucrose	1.67	2.98	.88	.00	.00	1.12
Starch	9.55	9.36	3.79	2.42	79.08	33.75
Pentoses	19.51	20.81	18.44	18.41	1.82	12.98
Cellulose	25.77	30.13	22.67	37.84	.98	20.79

The reducing sugars, found at the previous period, are largely converted into higher carbohydrates in the mature plant, although appreciable quantities exist in all parts of the plant, save the grain, and are greatest in the roots. Sucrose, likewise, largely disappears, there being none in the chaff and grain. In the stems the largest per cent of this substance is found, although there is only about one-fourth as much as at the second period. There is a general reduction in the percentages of true starch in all parts of the plant, except the grain, where it is stored in large amounts. A somewhat higher percentage of pentose sugars is found in the stems at maturity than formerly, other parts of the plant being found to contain about the same amounts as at the second period. The grain contains only 1.82 per cent of

[1] The carbohydrates mentioned above obviously do not include all of the so-called nitrogen-free extract in the rice plant. An investigation of this matter will be taken up later.

these bodies. In the total plant the percentage of pentoses is considerably less than at the second harvest, although the total amount in absolute units had slightly increased. Cellulose accumulates in the greatest quantities in the stems and chaff; in other parts of the plant but little change has taken place since the previous harvest. Attention is called to the slightly reduced percentage of cellulose in the total plant, which, of course, is traceable to the great elaboration of starch during this period.

Summing up the data for the three periods, we found considerable quantities of reducing sugars in all parts of the plant, except the grain, at every stage of growth. The greatest concentration of these bodies was found in the vegetative portion of the plant during early growth, which were later partially converted into higher carbohydrates. Sucrose increased from a mere trace, at the first period to 10.38 per cent in the stems and 5.01 per cent in the total plant at the second harvest. At maturity the high percentages of sucrose, previously found, were also largely converted into higher carbohydrates. In the total plant, at the third period, only 1.12 per cent sucrose was found.

Starch gradually increased throughout the development of the plant, there being, in the total plant, 8.21 per cent at the first period, 9.63 per cent at the second, and 33.75 per cent at the third. This body is temporarily stored in the roots and stems at the second period, which reserve is later transported to the grain, probably by first being reconverted into soluble sugars, and then transformed again into insoluble starch in the grain through the intervention of the leucoplasts of the protoplasm. However the translocation is brought about, there is certainly abundant evidence that some such transformation takes place.

At the second period the forces in the plant are at their highest activity, which results in seed formation and the consequent storage of food material in the grain. The high percentage of sucrose in the stems at this period may be looked upon as being in the current which is carried by diffusion and osmosis from the chlorophyll-bearing cells to the grain, where it is to be later transformed into reserve material for the nourishment of the seedlings of the next generation.

The little-understood pentose-forming bodies are formed in

considerable quantities in the early development of the plant, and reach a practical maximum at the second period. The data show the large extent to which these bodies contribute toward the make-up of the carbohydrate content of the plant. Cellulose, the framework of the plant, had also almost reached its maximum at the second period, and, in general, bears a close relation to the percentages of pentoses formed.

SUMMARY.

1. Fertilization with nitrogen, either with or without minerals, greatly increased the growth of the rice at all periods of its development. Minerals alone, or in conjunction with nitrogen, slightly increased the growth in the spring crop, but in the fall a corresponding decrease attended this application.

2. The percentage of nitrogen in the dry matter, at the first harvest of each crop, was considerably increased by nitrogen fertilizer, and was still further increased by the application of minerals, in addition to nitrogen. The percentage of nitrogen in the mature plant was not materially changed by the fertilizers.

3. The dry matter from the plat fertilized with the complete fertilizer contained at every period of growth a higher percentage of potash than from the plats fertilized with nitrogen only. The application of minerals alone resulted in a decreased absorption of potash.

4. The percentage of phosphoric acid in the dry matter at the first period was influenced somewhat by the fertilizers. In subsequent growth no difference in the phosphoric acid content was found.

5. The percentages of calcium and magnesium in the total plant were not greatly different at the several periods of growth. The calcium at maturity is stored largely in the leaves, while magnesium migrates to the grain.

6. The hydrolisable carbohydrates vary inversely with the percentage of nitrogen absorbed.

7. The rice plant contains a high percentage of nitrogen, phosphoric acid and potash during early growth, which percentages become gradually reduced during later development.

8. Seasonal variations greatly influence the growth of rice, and likewise produce noteworthy differences in the composition, especially during early growth.

9. The rice plant, by the time it is two-thirds grown, has normally taken up about four-fifths of its maximum nitrogen and phosphoric acid and nine-tenths of its potash, and therefore fertilizers should be applied before planting or at an early period of development. In common with other cereals, rice demands readily available plant food in abundance during early growth.

10. Rice can take up what may be looked upon as an excess of nutrients if these be present in sufficiently large quantities.

11. There is no return to the soil through the roots of rice of nitrogen, phosphoric acid, or potash, and any loss of these substances that this plant may sustain is most likely traceable to the leaching action of rains and dews.

12. Reducing sugars were found in notable quantities in the rice plant at all stages of growth and were greatest at the first period.

13. Sucrose, while present as a trace at the first period, occurred in the stems at the second period to the extent of 10.38 per cent. At maturity this had been largely converted into starch.

14. Starch gradually increases throughout the growth of the plant and at maturity is stored very largely in the grain.

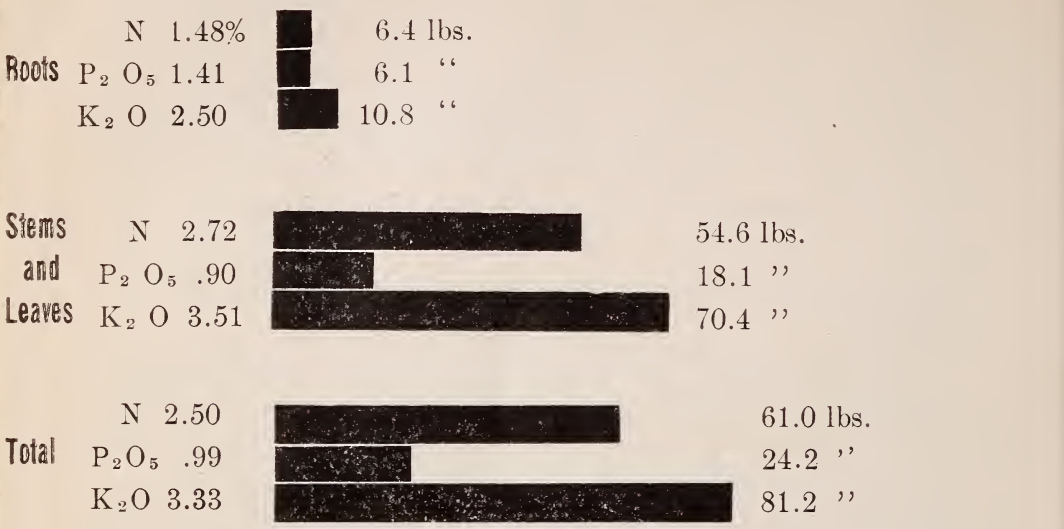
15. The pentose-forming bodies constitute a large percentage of the carbohydrates of the rice plant at every stage of growth and reach a practical maximum at the flowering stage.

16. Cellulose occurs in large quantities in all parts of the plant, except the grain, and likewise almost reaches a maximum at the second period.

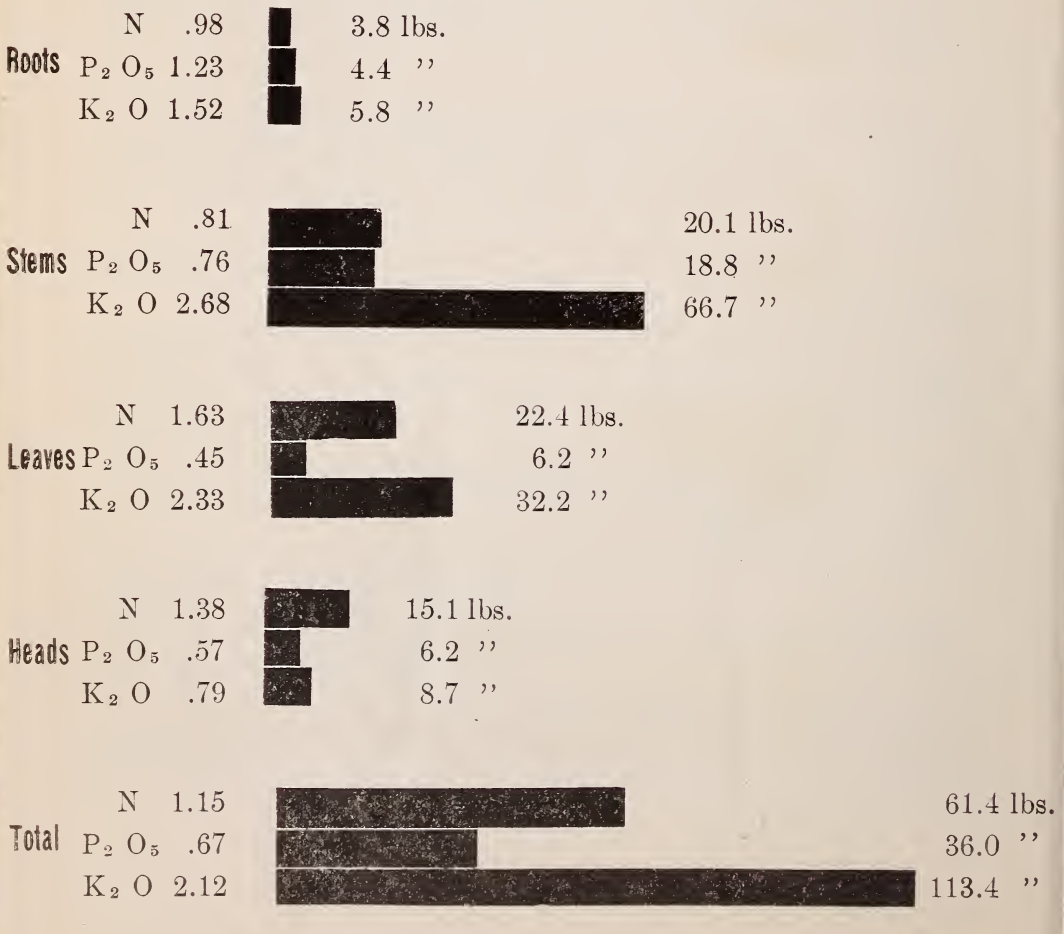
The above conclusions were drawn from a study of two different crops of rice and while the experiments are preliminary, the results should be considered as probable, though not definitely settled. In the near future the practical bearing of these experiments will be set forth in a publication of a more popular nature.

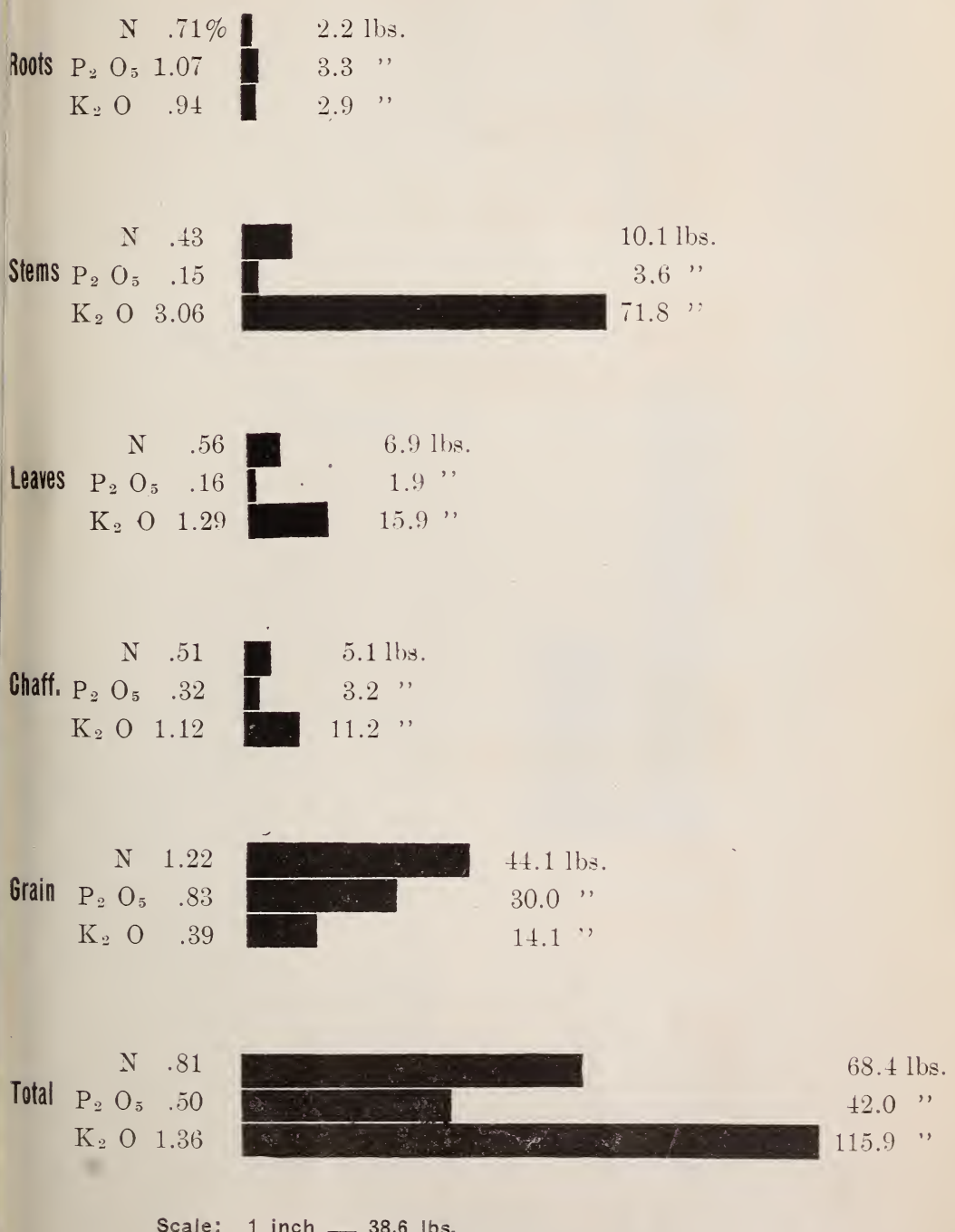
PLANT FOOD REMOVED BY RICE FROM ONE ACRE

First Harvest. (August 26, 1909).



Second Harvest. (September 13, 1909).



PLANT FOOD REMOVED BY RICE FROM ONE ACRE

Third Harvest. (October 9, 1909)